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ABSTRACT

An experiment was conducted to investigate the relationship between similarity of troubleshooting strategies and similarity of sets of utilities (i.e., numeric values representing beneficial troubleshooting outcomes) to assess the justification for using discrepancies between student and expert utilities as a basis for altering the Adaptive Computerized Training System (ACTS); ACTS is a new method developed by the Army Research Institute for providing electronic troubleshooting training. Thirty sets of utilities having specified similarities were generated into ACTS, and the effects of variations in utility similarity on strategy similarity were examined using simulated student and expert routines. A strong positive relationship between utility similarity and strategy similarity was obtained, which is a prerequisite to using discrepancies between student and expert utilities as a basis for adapting training. Because the experimental conditions were somewhat artificial, the strength of the relationship could be expected to be weakened in a "real world" training situation. (Author/CMV)

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by

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A SIMULATED TEST OF A DECISION THEORETIC INSTRUCTIONAL STRATEGY[1]

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INTRODUCTION

As military electronic systems have become more complex, the task of diagnosing and repairing them has become more difficult. For this reason, the Army Research Institute is developing and evaluating new methods for providing electronic troubleshooting training. One such method, which will be discussed shortly, is the Adaptive Computerized Training System (ACTS).

First, let us examine briefly the way electronic troubleshooting training is currently being conducted in the Army. Primarily, it is individually paced, hands-on, and equipment specific. The student is first taught the sequential step-by-step procedures necessary to locate a malfunction in a particular item of equipment, then practices and is tested on the actual equipment itself. This approach has several advantages. It insures that the student has mastered certain prerequisite skills, such as the use of test equipment. It teaches the student the physical layout of the equipment and the correspondence between the equipment and the circuit schematic diagram. Finally, it gives the student practice in disassembling and reassembling the equipment.

[1]The views and conclusions contained in this paper are those of the Author and should not be interpreted as necessarily representing the official policies of the U.S. Army or the Army Research Institute.

There are also several disadvantages. Since the training content is equipment specific procedures, rather than troubleshooting logic, there is little transfer of the skills acquired to similar or modified items of equipment. Also, a substantial amount of equipment, which could otherwise be used operationally, is required for training purposes. Instructors must spend large portions of their time inserting malfunctions into the equipment, rather than actually conducting training. Moreover, much student time is spent assembling, disassembling, and soldering the equipment, thus reducing the number of different equipment faults that they can experience during their training. Simple simulators could overcome some of these disadvantages, but would do little to provide the student with diagnostic skills which transfer to other items of equipment. The ACTS is being developed to provide these skills by basing training on an analysis of each student's decision process.

Simply, the ACTS is an "intelligent" simulator on which a student troubleshoots a complex electronic circuit by making various test measurements, replacing the malfunctioning part, and making final verification measurements. All of these interactions take place at a computer terminal. The "intelligent" component is an adaptive program which models the student's decision structure, compares this structure to that of an expert, and when complete, will adapt the instructional sequence and provide feedback to eliminate discrepancies between the two. An Expected Utility (EU) model of decision making is the basis of the models of both the student and expert troubleshooters.

The ACTS consists of four major components: (a) the task model; (b) the expert model; (c) the student model; and (d) the instructional model. The task model is a simulation of the circuit on which the student is to be trained. The expert model (a model of an expert troubleshooter) is an EU model which predicts the expert's measurement choices as he or she troubleshoots the circuit. It is developed through on-line observation of the expert's troubleshooting behavior. The student model, also an EU model, predicts the student's measurement choices. It is developed through on-line observation of the student's behavior as the student solves troubleshooting problems on the ACTS. The instructional model compares the expert and student models, determines discrepancies between the two and, when complete, will modify the instructional feedback and problem presentation sequence in order to reduce those discrepancies. Currently the instructional model can provide some adaptive feedback, but cannot modify the instructional sequence.

Troubleshooting a simulated electronic circuit on the ACTS involves selecting a series of actions from a limited set of possible actions, that is, take one of many possible test measurements, or replace one of several components. Each measurement can have from two to four possible outcomes (such as normal, high, or low), and each component can have two possible outcomes (good or bad). Each possible outcome has three properties. The first is the conditional probability of the concurrence of that outcome given the measurement outcomes previously obtained and given that the appropriate action is selected. The second property is the utility of the

outcome to the troubleshooter, i.e., what he gains or loses as a result of that outcome. Utility is subjective, but it should be related to the cost (in time or money) of taking that action. The third property is the amount of information that the outcome provides about the location of the fault. These properties are combined multiplicatively for each outcome and summed across the outcomes for each action to provide the EU for each action.

The probabilities and information gained are constant across individuals and can be determined objectively. The individual utilities and the EU for each action are determined separately for each individual (expert or student) by "tracking" their behavior as they solve a series of troubleshooting problems. (It is assumed that the student or expert selects the action with the highest EU.) As they do this, they are presented with updated probabilities of measurement outcomes before they select a measurement. Values for the probabilities and information gained are entered into the model before the individual starts, with the utilities set at some common arbitrary value (usually 100). The model chooses the action which has the highest EU. If the individual then chooses the same action, no changes in the utilities are made. However, if the action selected by the model differs from the action selected by the individual, the model utilities associated with the model choice are punished (decreased) and those associated with the individual choice are rewarded (increased). This process continues until the estimated utilities become stable. This will occur when the model is able to predict the choices of the individual accurately.

At this stage, an individual's performance is described by a set of numeric values (the utilities). A comparison of student and expert utilities for corresponding outcomes can potentially be used to diagnose a student's strengths and weaknesses, and hence be used to provide the student with diagnostic feedback, and to individualize the instructional sequence. However, it must first be shown that similar troubleshooting strategies result in similar sets of utilities, while different troubleshooting strategies result in different sets of utilities. For example, if a student troubleshoots a circuit by taking a sequence of measurements similar to that taken by the expert, the student utilities derived by the ACTS should be similar to those of the expert. Conversely, if the sequence of measurements taken by the student is different from that taken by the expert, the resultant utilities should also be different.

The purpose of this experiment was to investigate the relationship between similarity of troubleshooting strategies and similarity of sets of utilities. Results indicating that the two were positively related would provide a justification for using discrepancies between student and expert utilities as a basis for adapting ACTS training. Failure to find such a relationship, on the other hand, would indicate that there was no basis for using such techniques.

METHOD

Thirty sets of utilities having specified similarities were generated. Each set of utilities was then inserted into the ACTS, and the "simulated student" routine activated. The simulated student troubleshoots the

circuit according to the utilities it has been given, always selecting the measurement with the highest EU. Since the simulated student is perfectly consistent, i.e., always diagnoses the same fault through the same sequence of measurements, the solutions to a series of problems could easily be converted into a logic tree format. This format defined the strategy used by the simulated student. The effects of variations in utility similarity on strategy similarity were then examined.

The circuit used was a modularized power supply having 29 possible measurements, ten components, and a total of 96 possible outcomes (and utilities). The problem set consisted of 27 unique problems.

Utility similarity was defined as the product moment correlation between the corresponding utilities in each set.

The definition of strategy similarity used was based on the preliminary finding that consistent strategies generally require the use of less than one-half of the 29 possible measurements to solve a complete set of problems. Strategy similarity could therefore be calculated as a correlation (Ø coefficient) reflecting the similarity of the measurements used by any two strategies. (Other measures of strategy similarity, which took into account when and how frequently the various measurements were used, produced results identical to those of the measure just described, and therefore will not be discussed here.)

The procedure for generating the 30 sets of utilities was as follows. Five sets of 96 random numbers each, having a mean of approximately 100 and a standard deviation of approximately 15, were generated. These were designated the standard sets. For each standard set, five additional

sets of 96 numbers were generated, again having means and standard deviations of approximately 100 and 15, respectively. These five sets differed in their correlation (utility similarity) with the standard set, with each having a correlation of +.95, +.50, .00, -.50 or -.95.

Because the formulae used to generate the utility sets assumed that any two sets of random numbers were independent (i.e., had an intercorrelation of zero), the values of the means, standard deviations, and utility similarities differed somewhat from the desired values. However, the differences were slight, with none of the 25 utility similarities, one of the 30 means, and one of the 30 standard deviations differing significantly ($p<.05$) from the desired values.

Let us reconsider at this point the assumption being tested: similar troubleshooting strategies result in similar sets of utilities, while different troubleshooting strategies result in different sets of utilities. Experimentally, this has been reversed, with utilities (the independent variable) generating strategies, rather than vice versa. This is because it was relatively simple to generate sets of utilities with specified similarities, but generation of strategies with specified similarities would have been considerably more complex. However, if the assumption is correct, utility sets having high similarity should produce strategies having higher similarity than strategies produced by utility sets having low similarity.

RESULTS

The correlation between utility similarity and strategy similarity was +0.81, ($p<.001$). In other words, utility similarity accounted for over 65% of the variance in strategy similarity. Strategy similarity decreased as utility similarity decreased. For utility similarities of +0.95, +0.50, 0.00, -0.50, and -0.95, mean strategy similarities were +0.74, +0.44, +0.26, +0.18, and +0.07, respectively.

Closer examination of the data raised two issues. First, it was apparent that there was considerable variation among utility sets, that is, large differences in strategy similarity were obtained at the same values of utility similarity. Second, there appeared to be some tendency toward a curvilinear relationship between utility similarity and strategy similarity. In order to determine whether a significant curvilinear component was present, and to determine the extent to which the utility sets varied in terms of strategy similarity, data were re-analyzed using analysis of variance. The particular analysis of variance model used was a one factor (utility similarity) repeated measurements design, with additivity assumed (Myers, 1966, pp. 153-156). The utility sets were treated as subjects. Five levels of utility similarity (+.95, +.50, .00, -.50, and -.95) were used. The utility similarity effect was further analyzed to determine the significance of linear and higher-order trends (Myers, 1966, pp. 348-357). The estimated proportion of variance accounted for, ω^2, was calculated for each significant effect (Hayes, 1963, pp. 406-408).

As would be expected on the basis of the correlational analysis, the effect of utility similarity was highly significant ($F=37.59$, $df=4,16$, $p<.001$) and accounted for 68% of the experimental variance. The linear component of the relationship between utility similarity and strategy similarity was significant ($F=150.12$, $df=1,16$, $p<.001$), while the non-linear component approached, but did not reach, significance ($F=3.22$, $df=3,16$, $.05 < p < .10$). The effect of utility sets was also significant ($F=11.75$, $df=4,16$, $p<.001$), accounting for 20% of the experimental variance. Thus, as suspected, there was considerable variation among utility sets.

DISCUSSION

For the values of utility similarity considered, a strong relationship was found between utility similarity and strategy similarity, as both were defined in this study. Furthermore, the relationship between utility similarity and strategy similarity was predominately linear, although a slight curvilinear component was suggested.

Under the conditions of this study, then, the greater the similarity between a set of utilities and a criterion (or standard) set, the more similar their strategies will be. If one set of utilities is that of a student, and the criterion set is that of an expert, the similarity of their strategies will increase as the student utility set becomes more similar to that of the expert. However, the conditions of this study

were different from those that would be found in a "real world" training situation, and the overall effect of those differences would be to produce stronger relationships between utility and strategy similarity in the experimental than in the training setting.

The rationale for investigating the relationships between strategy similarity and utility similarity in an artifical situation was twofold: (a) only limited resources were available; and (b) if a relatively strong relationship between utility and strategy similarity could not be discovered in the artificial situation, it certainly would not be discovered in the training situation. Thus the experimental results are a necessary, but not sufficient, prerequisite to obtaining similar results in the training situation.

It is appropriate to consider why a stronger relationship between utility and strategy similarity would be expected in the artifical situation than in the training situation. First, human troubleshooting behavior is not perfectly reliable. Although each individual may have a "true" strategy which can be represented by a logic tree, deviations from the true strategy can be expected. This inconsistency in human performance precludes obtaining a perfect relationship between utilities and strategies: hence, utilities will not predict human performance perfectly (May, Crooks, and Freedy, 1978).

Second, as previously noted this study was run "in reverse." Utilities generated strategies, which is the opposite of what would occur in the training situation. In actual applications the student (or expert) model will necessarily produce identical utilities for identical (and

"error-free") strategies only if behavior is observed over the same sequence of problems. Otherwise, differences between the utilities may occur.

A note of caution concerning the variation among utility sets is also in order. This variability could be of practical importance in situations in which multiple sets of expert utilities have been developed. This would occur when there are several equally effective ways to troubleshoot the same circuit. If a student's utilities are more similar to those of Expert A than to those of Expert B, it does not necessarily follow that the student's strategy will be more similar to that of Expert A than to that of Expert B.

Summary

A strong positive relationship between utility similarity and strategy similarity was obtained. This is a prerequisite to using discrepancies between student and expert utilities as a basis for adapting training.

Because the experimental conditions were somewhat artificial, the strength of the relationship between utility similarity and strategy similarity could be expected to be attenuated in a "real world" training situation.

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